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5 SENSITIVITY ANALYSIS

Sensitivity analysis is the process of varying model input parameters and evaluating how model output changes with such variations. The significance of model sensitivity analysis is two-fold:

1. It provides information on the behavior of model output to input parameters which, in turn, can be used in model calibration;
2. It gives insight in establishing priorities related to future data collection efforts.

Sensitivity analysis is distinguished from that of uncertainty analysis. Sensitivity analysis is a measure of the relative importance that each input parameter has on the range of simulated outputs. Uncertainty analysis quantifies the confidence in particular output variables. While sensitivity analysis is often limited to parameter sensitivity, uncertainty may be generated by a number of factors including: 1) parameter uncertainty, 2) model spatial and temporal resolution, 3) availability and quality of data, and 4) model algorithm. This chapter deals with sensitivity analysis as applied to the model. The next chapter discusses model uncertainty analysis at a similar level of detail.

5.1 METHODOLOGY

The sensitivity of the output variables to variations in input parameters is estimated by the traditional approach of varying one parameter at a time. A sensitivity matrix is set up that summarizes the response at each observation point to changes in individual parameters. Model response is expressed in terms of simulated nodal stages or canal flows within the model domain. The following input parameters (as described in the listed reference sections) are systematically varied universally over the whole model domain in order to analyze model output sensitivity:

1. Effective roughness coefficient for overland flow (MAN); Section 2.4.2
2. Potential ET for wetland (WPET); Section 2.3.1
3. Potential ET for coastal areas (CPET); Section 2.3.5
4. Groundwater hydraulic conductivity (GWHC); Section 2.5.4
5. Levee seepage coefficient (SEEP); Section 2.5.3
6. Detention parameter (DET); Section 2.4.2
7. Canal-groundwater hydraulic conductivity (CHHC); Section 2.5.2
8. Storage coefficient (STOC); Section 2.5.4

Since the ranges of acceptable parameter values to be used for sensitivity analysis are not available in literature, parameters were varied over a range for which the model calibration was assumed to remain valid (Loucks and Stedinger, 1994). During calibration, acceptable ranges of variation for input parameters were decided based on the model output reaction to the change of parameters.

A sensitivity or influence matrix is set up that summarizes the response at selected observation points to changes in individual parameters. Each element of this matrix can be represented by the following relationship (Trimble, 1995a):

$$\alpha_{ij} = \frac{\partial y_j}{\partial x_i} \approx \frac{y_j^c - y_j^o}{\Delta x_i} \tag{5.1.1}$$

for $i = 1, 2, \ldots, n$ and $j = 1, 2, \ldots, m$; where:

- α_{ij} = sensitivity of model output at observation point j to change in calibrated parameter x_i;
- y_j^c = simulated output at observation point j when calibrated parameter x_i is changed by an incremental value Δx_i;
- y_j^o = simulated output at observation point j using the calibrated parameter x_i;
- Δx_i = incremental change in parameter x_i;
- n = number of parameters tested;
- m = number of observation points evaluated.

A matrix factorization technique – single value decomposition (SVD) – is applied to the sensitivity matrix in order to investigate the relationships between the parameters, and isolate groups of parameters that are dependent on one another.

5.2 RESULTS OF SENSITIVITY ANALYSIS

Sensitivity of model output by varying key input parameters is quantified by calculating the bias and root mean square error (rmse) of the simulated water levels versus observed water levels at selected model nodal locations (as described in Chapter 4). For each parameter, a series of model runs were completed to determine a range of acceptable values such that each parameter value within the range can be used without significantly affecting the calibration. The results are grouped by magnitude of errors (expressed in terms of bias and rmse) in each region. By using this method of analysis, one is able to determine whether the variation of a parameter affects all monitoring points or just a subset of monitoring points.

As an example, Figure 5.2.1 and Figure 5.2.2 show the model reaction in terms of bias and rmse for Wetland Potential Evapotranspiration (WPET) in the WCAs. The value of WPET is changed to 20%, 50%, 80%, 100% (the calibrated value), 110%, 120%, 150% and 200% of the calibrated value.

As seen from the plots, a change in the parameter WPET has a strong influence in the gages in the WCAs. When the value of WPET is decreased (20%, 50%, 80% of the calibrated value), both the bias and the rmse of the gages in the WCAs increased in the positive direction. When the value of WPET is increased (110%, 120%, 150% and 200% of the calibrated value), bias of the gages in WCAs increases in the negative direction; the rmse increases. To keep both bias and rmse in WCAs small, it's preferable to have a small change of WPET.

Figure 5.2.3 shows the reaction of the output stages in WCAs at the key percentile point (5th percentile; lower quartile; median; upper quartiles and 95th percentile) for each parameter change. It can be seen that increasing or decreasing the parameter WPET slightly would not increase the bias immensely. If the change of WPET is within $\pm 10\%$, the calibration of the model won't be affected significantly. To keep the modeling output valid, the recommended change of WPET is ±10%.

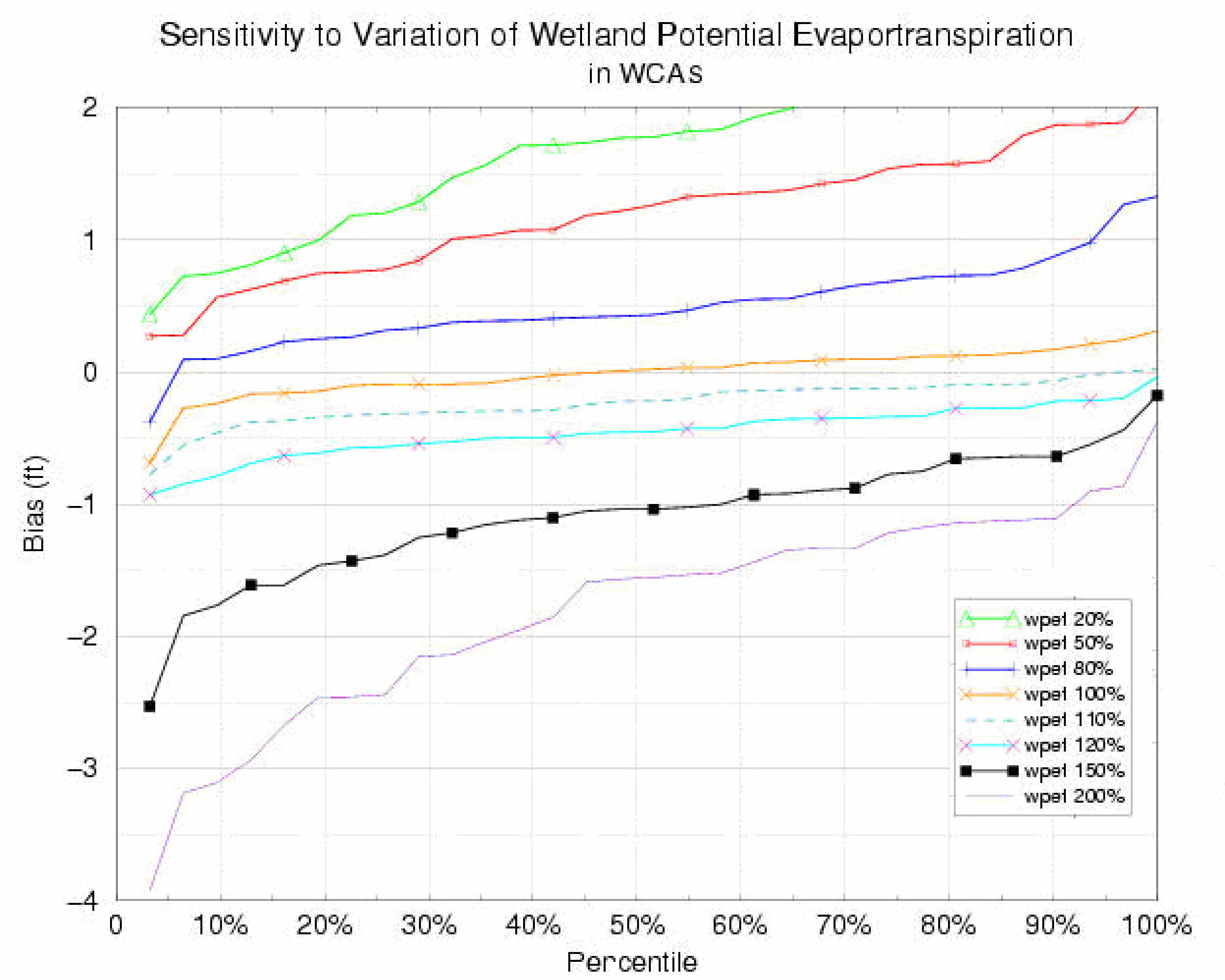

Figure 5.2.1 Sensitivity in terms of Bias to Variation of Wetland Potential Evapotranspiration (WPET) in WCAs

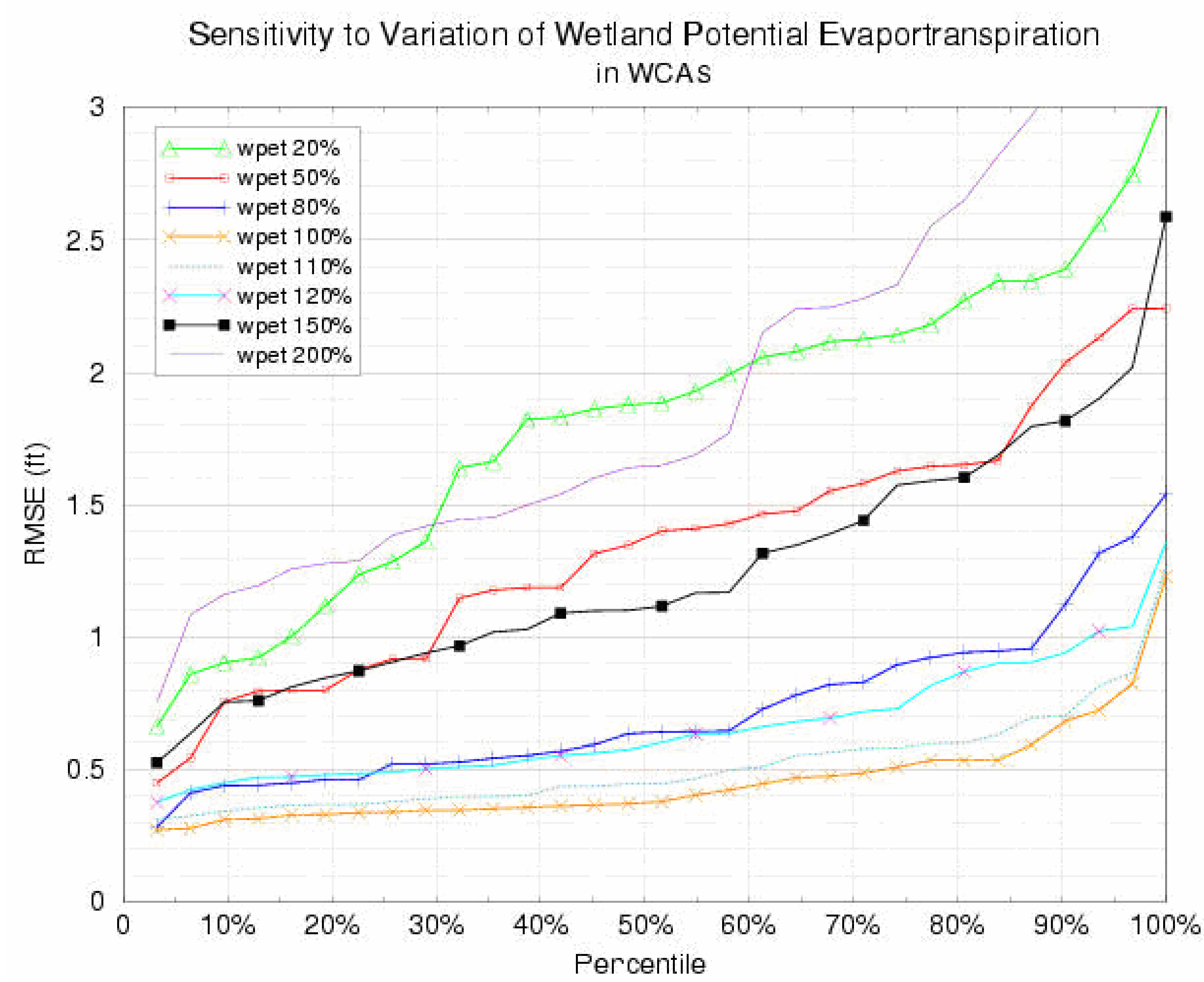

Figure 5.2.2 Sensitivity in terms of RMSE to Variation of Wetland Potential Evapotranspiration (WPET) in WCAs

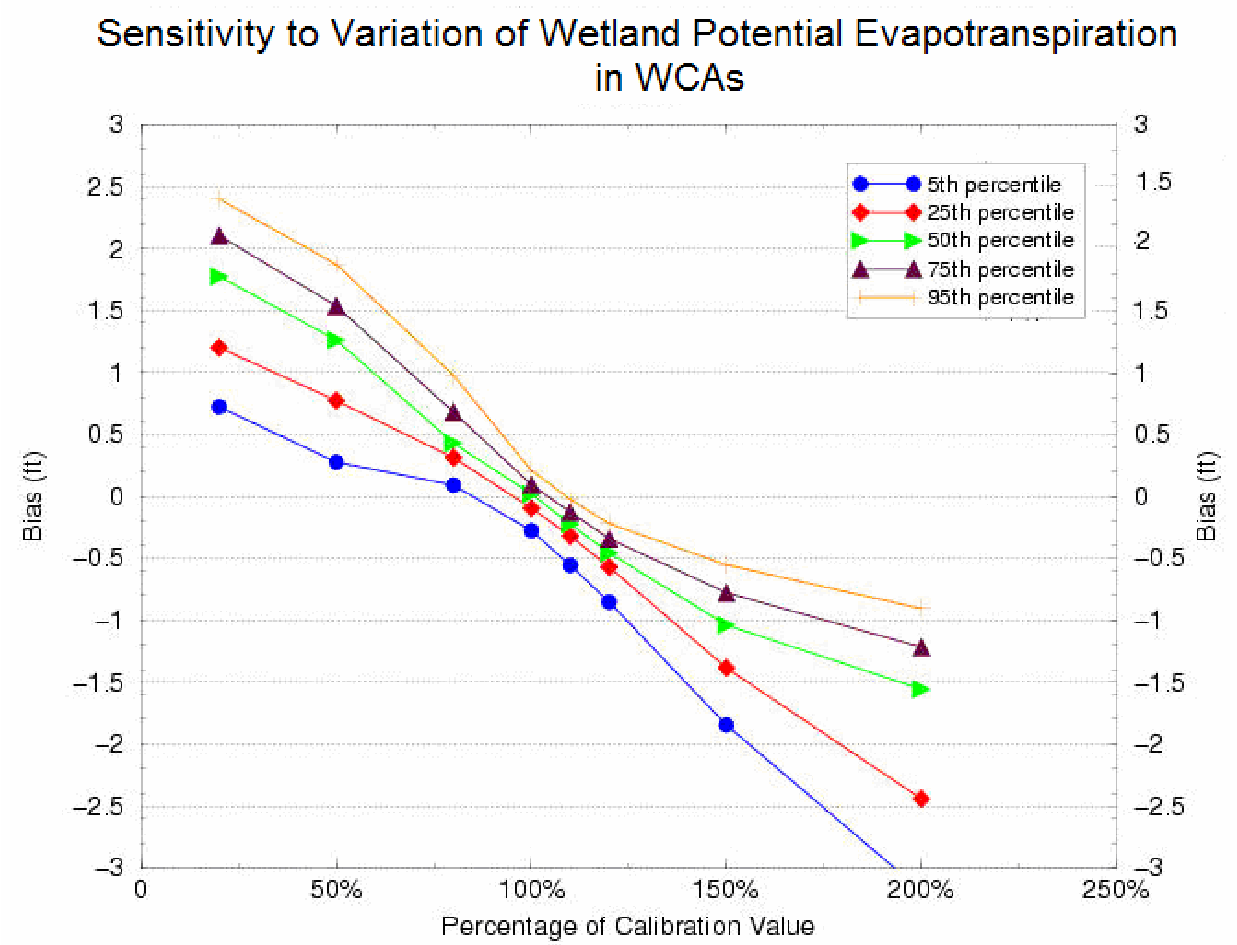

Figure 5.2.3 Sensitivity Percentile in terms of Bias to Variation of Wetland Potential Evapotranspiration (WPET) in WCAs

Based on the reaction of the model output, a ± 50% variation of the calibration value is recommended (Trimble, 1995a) for all parameters except the coastal and wetland PET. For Coastal PET, a ± 20% change from the calibrated value is recommended to represent the 95% confidence value; while for WPET, as shown in the plots, a ± 10% change from the calibrated value is recommended. The recommended parameter variation is summarized in Table 5.2.1.

Table 5.2.1 Parameter variation value at 95% confidence level

Parameter	Recommended parameter variation at 95% confidence level
WPET	± 10%
GWHC	± 50%
CHHC	± 50%
DET	± 50%
SEEP	± 50%
MAN	± 50%
CPET	± 20%
STOC	± 50%

Figures 5.2.4 to Figure 5.2.10 show the components of the sensitivity matrix for stages at different monitoring points for different regions within the model domain as follows:

BCNP: Big Cypress National Preserve
WCAs: Water Conservation Areas
ENP: Everglades National Park
LEC SA1: Lower East Coast Service Area 1
LEC SA2: Lower East Coast Service Area 2
LEC SA3: Lower East Coast Service Area 3
Canals: Representative canals throughout the model domain

Equation 5.1.1 is modified as follows:

$$\alpha_{ij} = \frac{\partial y_j}{\partial x_i} \approx \frac{O_{95} - O_{calibrated}}{P_{95} - P_{calibrated}} \tag{5.2.1}$$

for $i = 1, 2, \ldots, n$ and $j = 1, 2, \ldots, m$; where:

O_{95} = output variable value (stage) when input parameter is set at 95% confidence value;
$O_{calibrated}$ = output variable value when input parameter is set at the calibrated value;
P_{95} = parameter value at the 95% confidence value of the parameter likelihood distribution;
$P_{calibrated}$ = parameter at the calibrated value.

The response of the output variables corresponds to the normalized input parameter values (change in stage expressed in terms of feet increase or decrease based on a 100% change in parameter value. The change in output stage is divided by the percentage of the input parameter change to get the normalized value) is shown in Figure 5.2.4 to Figure 5.2.10.

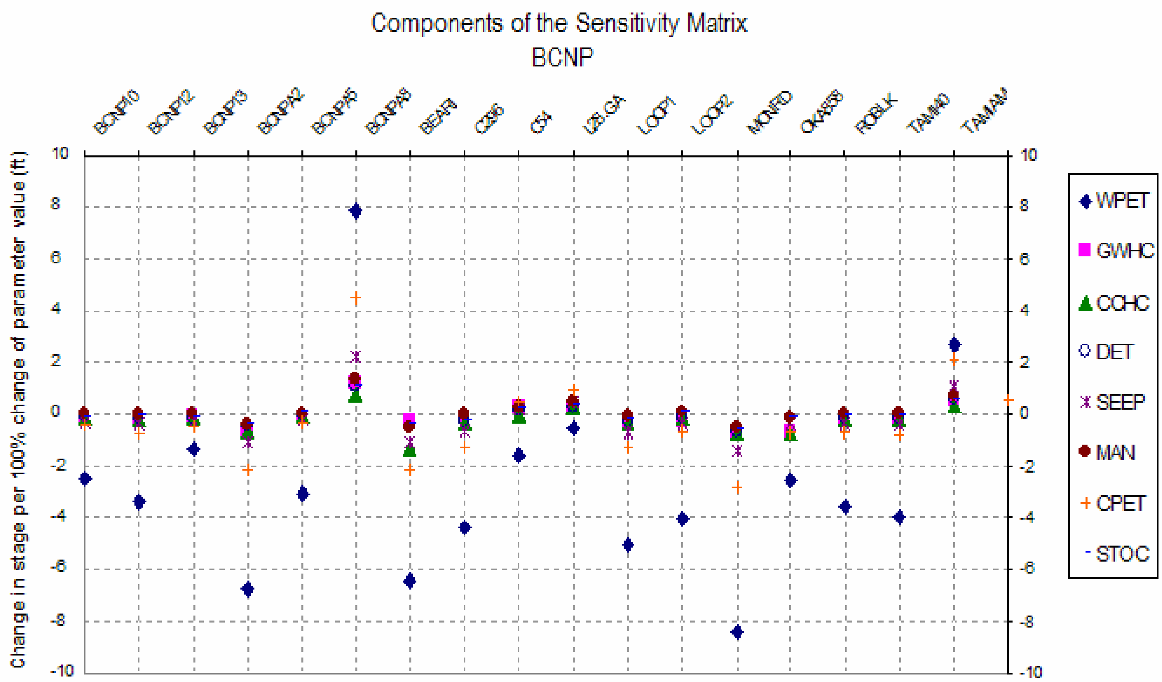

Figure 5.2.4 Components of the Sensitivity Matrix for BCNP

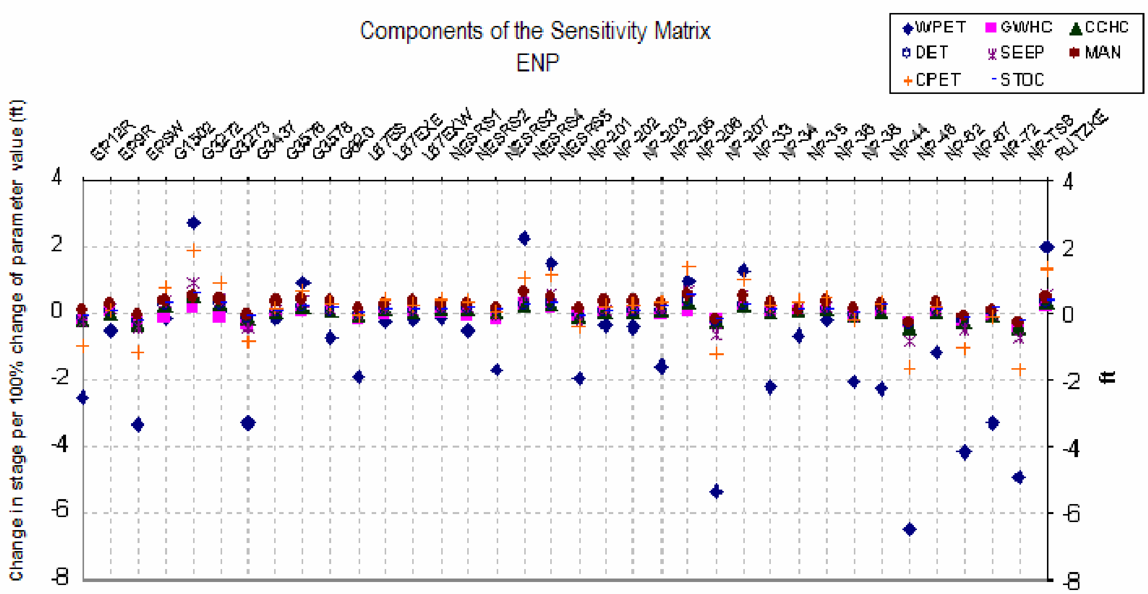

Figure 5.2.5 Components of the Sensitivity Matrix for ENP

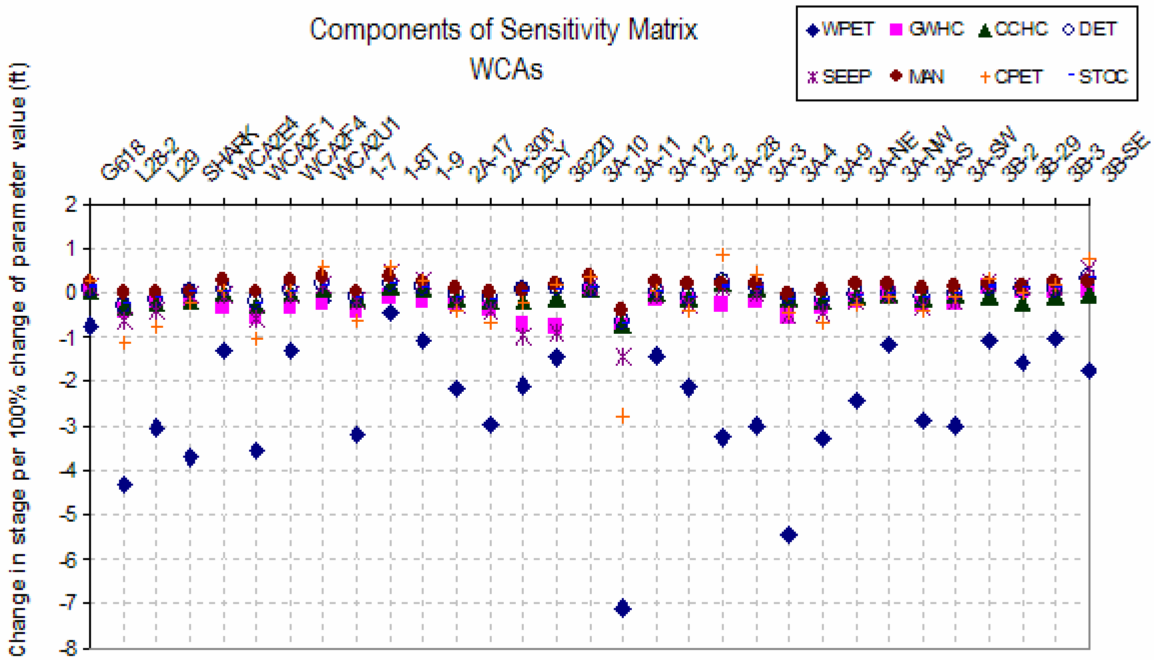

Figure 5.2.6 Components of the Sensitivity Matrix for WCAs

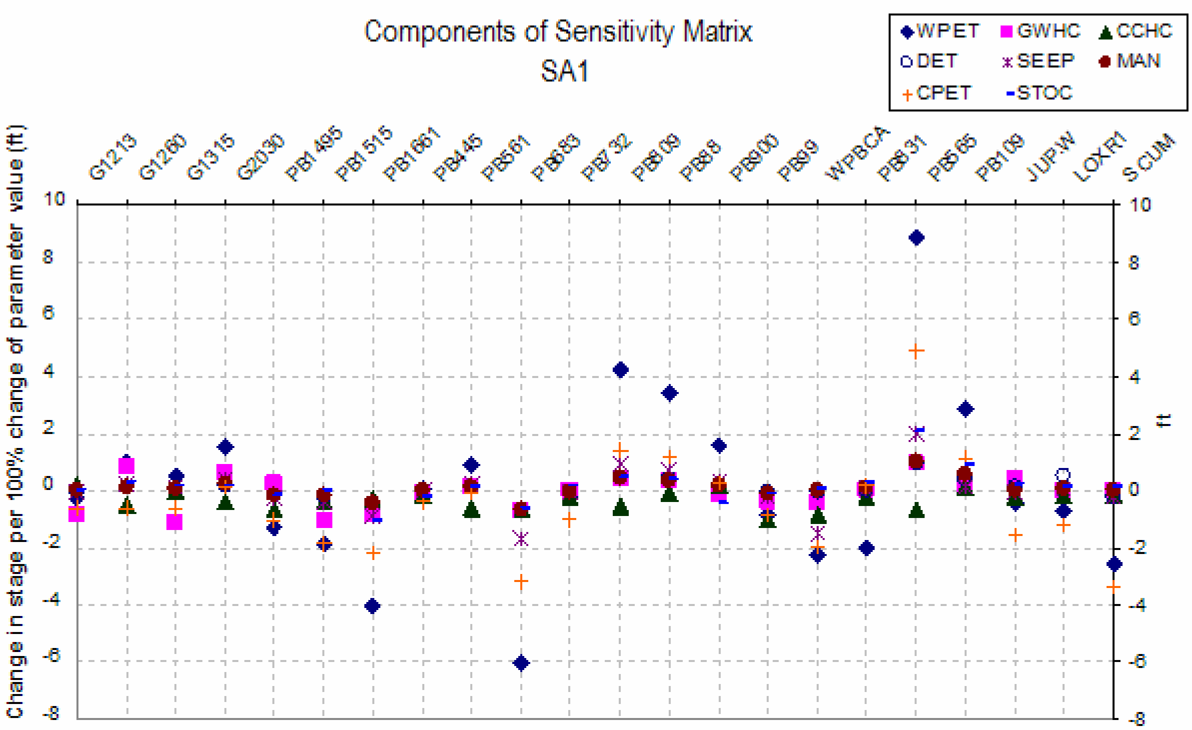

Figure 5.2.7 Components of the Sensitivity Matrix for LEC SA1

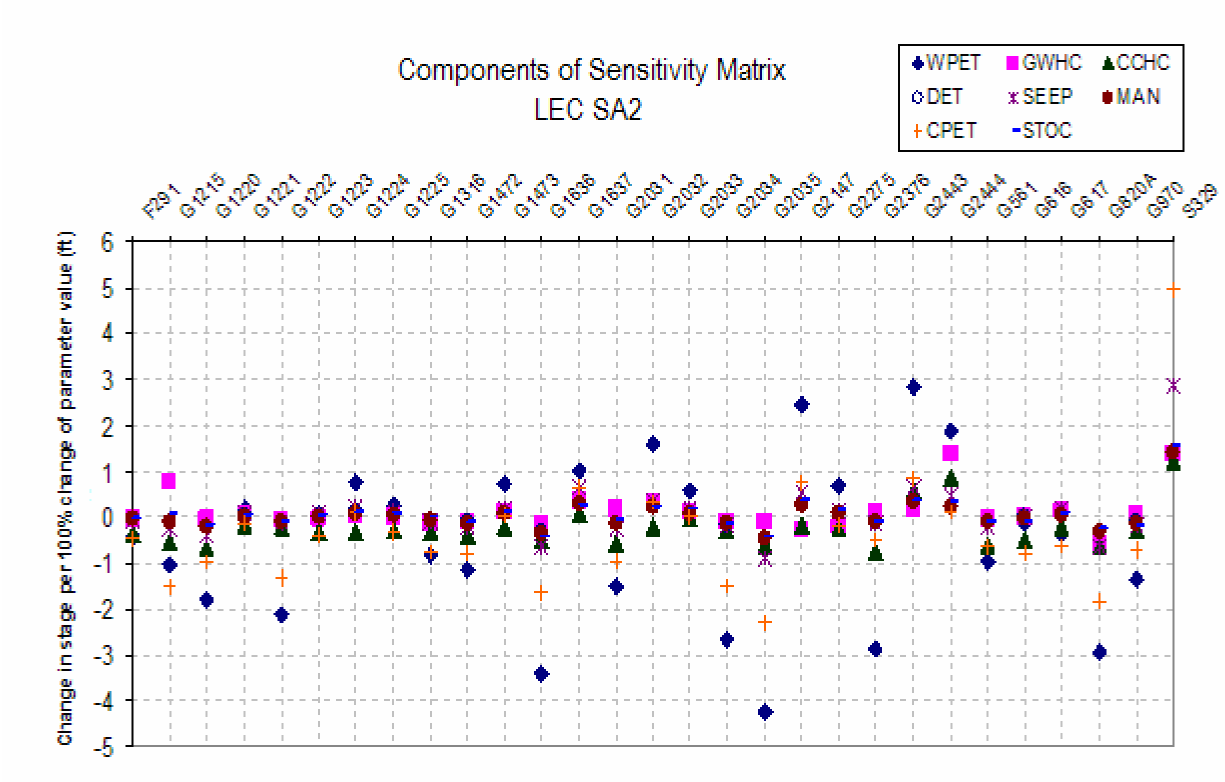

Figure 5.2.8 Components of the Sensitivity Matrix for LEC SA2

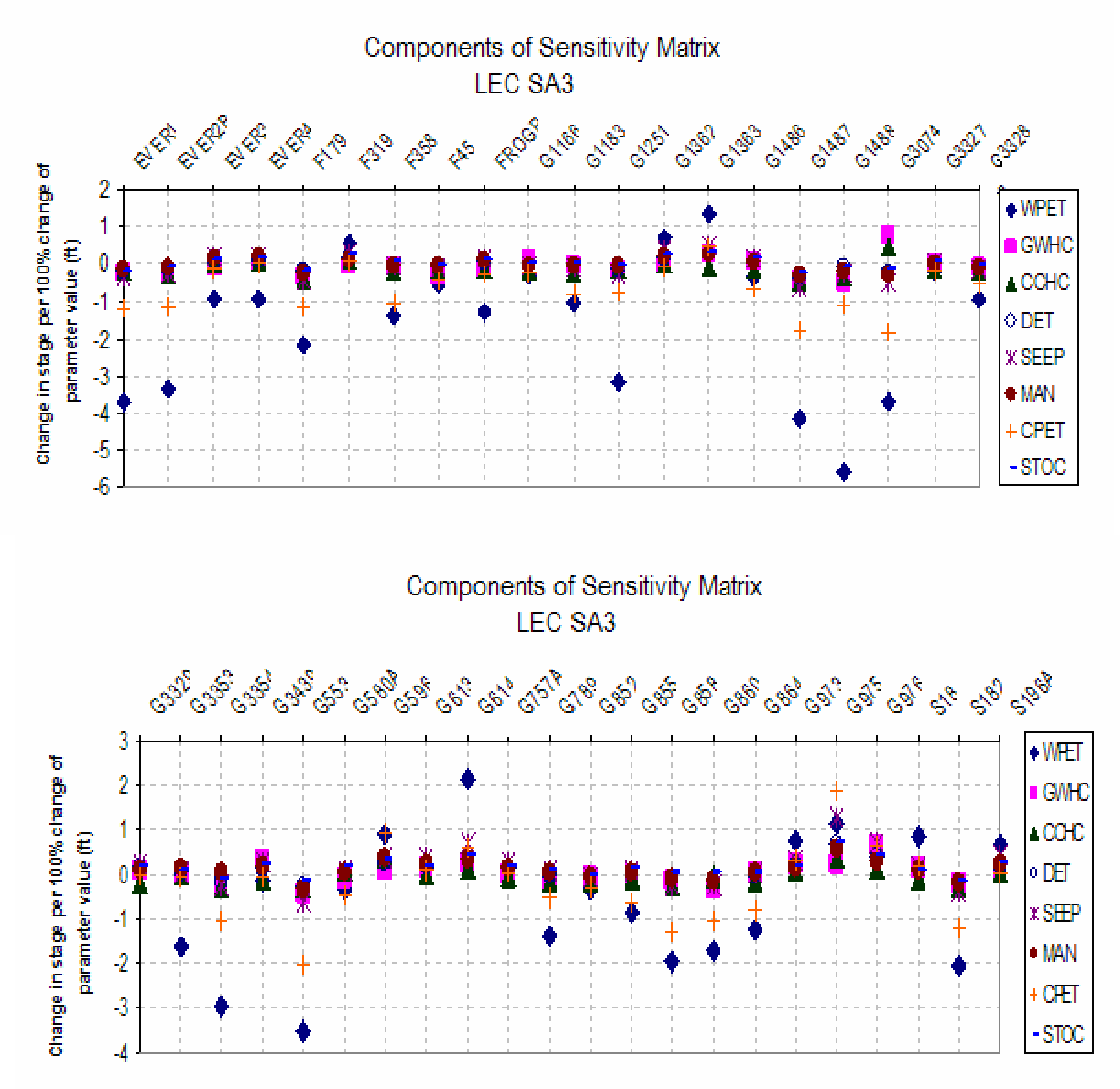

Figure 5.2.9 Components of the Sensitivity Matrix for LEC SA3

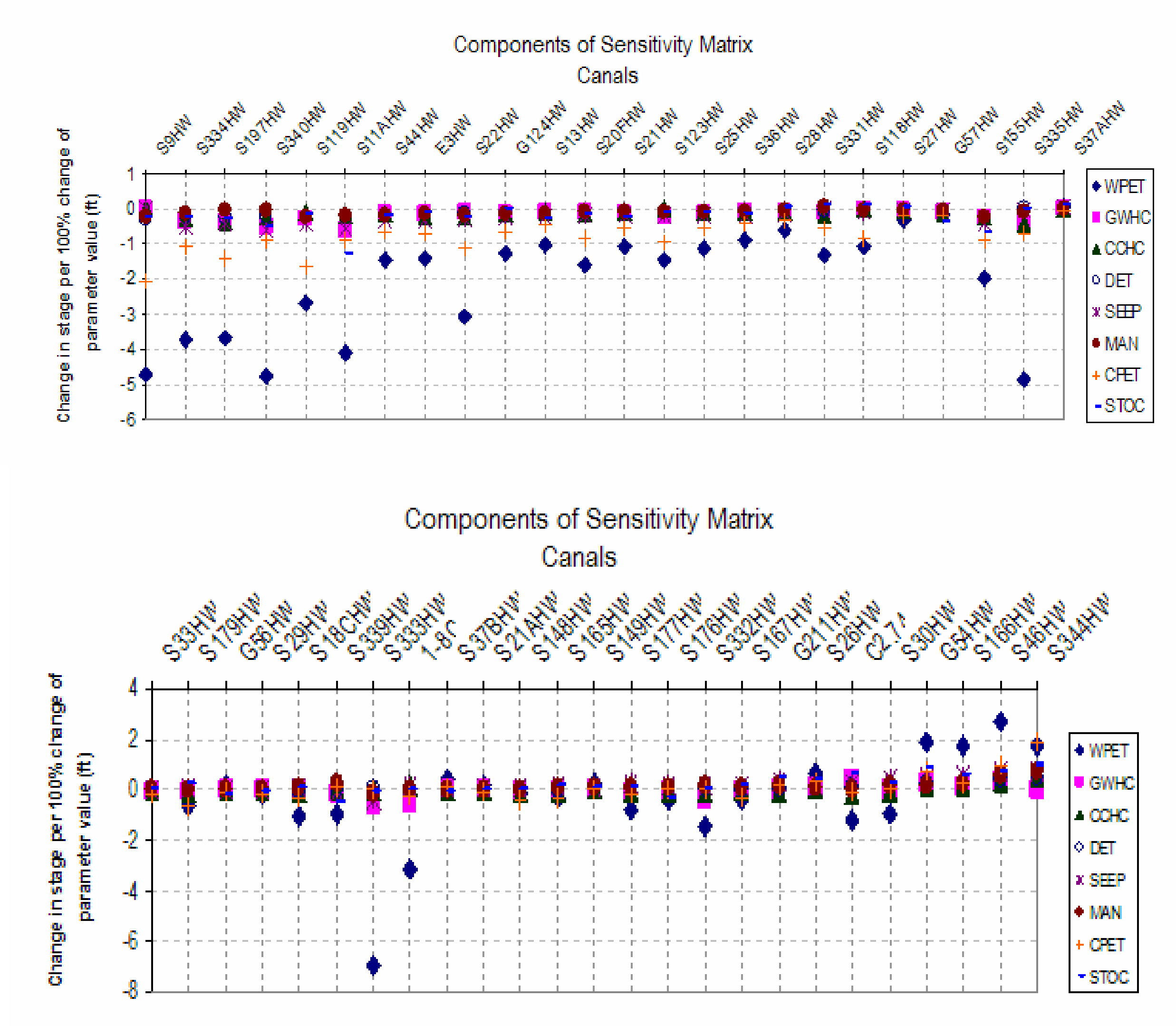

Figure 5.2.10 Components of the Sensitivity Matrix for Canals

The following observations can be made regarding Figures 5.2.4 – 5.2.10:

1. All regions are most sensitive to Wetland PET (WPET), especially BCNP, ENP, WCAs, and LEC SA3.
2. PET for coastal areas (CPET) also has a strong influence upon all regions, especially LEC areas.
3. Canal-Groundwater Hydraulic Conductivity (CHHC) has a strong influence on BCNP, LEC SA1, SA2 and SA3. The other regions, ENP, WCAs and Canals are not sensitive to CHHC.
4. Effective Roughness Coefficient for Overland Flow (MAN) has a relative stronger influence in BCNP, ENP and WCAs. Canals and LEC SAs only have slight impact from the variation of MAN value.
5. All regions are quite sensitive to the variation of Groundwater Hydraulic Conductivity (GWHC) value.

6. **Levee Seepage (SEEP) variation affects the WCAs and LEC SA1 the most. All the other regions are just slightly influenced.**
7. **Detention Parameter (DET) has a slight influence upon LEC SA1 and SA2. All the other regions are not sensitive to this parameter.**
8. **Storage Coefficient (STOC) affected all the regions except WCAs.**

A product of the SVD method is the parameter resolution matrix, as shown in Table 5.2.2, which is a measure of the independence of parameters used in a model. For the SFWMM, the resolution matrix is well resolved, all the elements are in the order of 10^{-8}, which means that each parameter is uniquely determined and should be treated separately as far as its influence in determining model output sensitivity and uncertainty.

Table 5.2.2 Parameter Resolution Matrix

	WPET	**GWHC**	**CCHC**	**DET**	**SEEP**	**MAN**	**CPET**	**STOC**
WPET	1.0	10^{-8}	10^{-8}	10^{-10}	10^{-8}	10^{-8}	10^{-8}	10^{-8}
GWHC	10^{-8}	1.0	10^{-8}	10^{-7}	10^{-9}	10^{-8}	10^{-8}	10^{-8}
CCHC	10^{-8}	10^{-8}	1.0	10^{-7}	10^{-7}	10^{-8}	10^{-8}	10^{-9}
DET	10^{-10}	10^{-7}	10^{-7}	1.0	10^{-7}	10^{-8}	10^{-7}	10^{-9}
SEEP	10^{-8}	10^{-9}	10^{-7}	10^{-7}	1.0	10^{-7}	10^{-8}	10^{-7}
MAN	10^{-8}	10^{-8}	10^{-8}	10^{-8}	10^{-7}	1.0	10^{-8}	10^{-8}
CPET	10^{-8}	10^{-8}	10^{-8}	10^{-7}	10^{-8}	10^{-8}	1.0	10^{-8}
STOC	10^{-8}	10^{-8}	10^{-9}	10^{-9}	10^{-7}	10^{-8}	10^{-8}	1.0

Additional useful information that can be derived from SVD method is the correlation matrix, as shown in Table 5.2.3. This matrix shows that there is only modest correlation between model input parameters. The range of values does not indicate positive or negative correlation. They range from 0.0 for no correlation and 1.0 for perfect correlation. Effective Roughness Coefficient and Detention Depth show a relatively stronger correlation (0.27). When Detention Depth is increased, a corresponding increase in the effective roughness coefficient would be necessary to prevent build-up of water to maintain a valid calibration. This conclusion is confirmed by the effective roughness coefficient equation $N=(A)(POND^b)$ applied in the SFWMM, where *POND* is the ponding depth.

Table 5.2 3 Parameter Correlation Matrix

	WPET	**GWHC**	**CCHC**	**DET**	**SEEP**	**MAN**	**CPET**	**STOC**
WPET	1.00	0.10	0.01	0.05	0.03	0.19	0.19	0.00
GWHC	0.10	1.00	0.00	0.01	0.10	0.00	0.01	0.02
CCHC	0.01	0.01	1.00	0.00	0.01	0.01	0.08	0.04
DET	0.01	0.01	0.00	1.00	0.18	0.27	0.04	0.10
SEEP	0.03	0.10	0.01	0.18	1.00	0.01	0.01	0.01
MAN	0.19	0.00	0.01	0.27	0.01	1.00	0.04	0.03
CPET	0.19	0.01	0.08	0.04	0.01	0.04	1.00	0.00
STOC	0.00	0.02	0.04	0.10	0.01	0.03	0.00	1.00